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THE KINETIC STABILIZER: A ROUTE TO SIMPLER TANDEM MIRROR SYSTEMS?

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As we enter the new millennium there is a growing urgency to address the issue of finding long-range solutions to the world's energy needs. Fusion offers such a solution, provided economically viable means can be found to extract useful energy from fusion reactions. While the magnetic confinement approach to fusion has a long and productive history, to date the mainline approaches to magnetic confinement, namely closed systems such as the tokamak, appear to many as being too large and complex to be acceptable economically, despite the impressive progress that has made toward the achievement of fusion-relevant confinement parameters. Thus there is a growing feeling that it is imperative to search for new and simpler approaches to magnetic fusion, ones that might lead to smaller and more economically attractive fusion power plants.

In any search for better approaches to magnetic fusion it is important to keep in mind the lessons learned in the 50 years that fusion plasma confinement has been studied. One of the lessons learned is that "closed" and "open" fusion devices differ fundamentally with respect to an important property of their confinement, as follows: Without known exception closed systems such as the tokamak, the stellarator, or the reversed-field pinch, have been found to have their confinement times limited by non-classical, i.e., turbulence-related, processes, leading to the requirement that such systems must be scaled-up in dimensions to sizes much larger than would be the case in the absence of turbulence. By contrast, from the earliest days of fusion research, it has been demonstrated that open magnetic systems of the mirror variety can achieve confinement times close to that associated with classical, i.e., collisional, processes. While these good results have been obtained in both axially symmetric fields and in non-axisymmetric fields, the clearest cases have been those in which the confining fields are solenoidal and axially symmetric.. These observations, i.e., of confinement not enhanced by turbulence, can be traced theoretically to such factors as the absence of parallel currents in the plasma, and to the constraints on cross-field particle drifts imposed by the adiabatic invariants governing confinement in axially symmetric open systems.

In the past the known instability of axially symmetric open systems to MHD interchange modes has been seen as a barrier to their use for plasma confinement. However, theory [1] predicts MHD-stable confinement is achievable if sufficient plasma is present in the "good curvature" regions outside the mirrors. This theory has been confirmed by experiments on the Gas Dynamic Trap mirror-based experiment at Novosibirsk [2]. In this experiment the density of the interior confined plasma was sufficiently high that the effluent plasma was dense enough to stabilize the interior plasma, up to beta values of 30 percent. In this paper a new way of exploiting this stabilizing principle, involving creating a localized “stabilizer plasma” outside a mirror, will be discussed. The technique involved here in forming the localized plasma peak is the same as one earlier proposed, where it was to be used to create the “plugs” of a tandem-mirror system, called the “Kinetic Tandem.”[3] It works in the following way: To create the stabilizing plasma ion beams are injected along the field lines in such a way as to be reflected before they reach the mirrors, thus forming at their turning points a localized peak in the plasma density in a region of positive field-line curvature [4].

It will be shown in the paper that the power required to produce such stabilizing plasmas is much less than the power per meter of fusion power systems that might employ this technique. In an example calculation, a fusion plasma generating 45 MW of fusion power is found to require only 200 kW of Kinetic Stabilizer beam power to stabilize the plasma against MHD interchange modes. Also, it is shown that the stabilizing effect can be optimized by specially shaping the flux surfaces exterior to the mirror (where the Stabilizer plasma is located). For example, if the flux surface is “trumpet-shaped,” that is, if it has the shape of a cone (zero curvature), followed by an outwardly flaring surface (large positive curvature) where the Stabilizer plasma is located, the stabilizing effect of the peaked plasma is enhanced.

Use of the Kinetic Stabilizer idea may therefore permit the construction of tandem mirror fusion power systems that are much smaller and simpler than those that use non-axisymmetric fields to achieve MHD stability. If the plasma confinement in Kinetic Stabilizer-based tandem mirror systems approaches the “classical” confinement times achieved in earlier axi-symmetric open-ended systems the possibility is opened up of building magnetic fusion power systems with power outputs of order 100 MW and with physical dimensions that are much smaller than those projected for tokamak-based fusion power systems. Also, because the plasma physics issues should be much less complex than those encountered in turbulence-dominated closed systems, the investigation of Kinetic Stabilizer-based tandem-mirror systems en route to fusion power systems should be far less arduous and time consuming, both from an experimental and a computational standpoint.

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